The effect of soluble active agents on film flow

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ABSTRACT

We investigate the modifications in the dynamics of liquid film flow, resulting from the addition of soluble surfactants. We use aqueous solutions of iso-propanol (IP) and of sodium dodecyl sulfate (SDS), and perform experiments in two inclined flow facilities, a 3000 mm long by 450 mm wide channel and a 800 mm long by 250 mm wide channel. Both facilities may operate with adjustable width up to the above maximum values. Regular disturbances with frequency in the range 0.15-1.50 Hz are introduced at the inlet, and their temporal evolution at various downstream locations is recorded by conductance probes.

Recent experiments [1] indicate that, unlike classical predictions based on Squire's theorem, the primary instability of film flow in channels of finite width depends on surface tension. Using IP solutions of varying concentrations, we have shown [2] that this dependence scales with Kapitza number, which expresses the ratio of capillary to viscous stresses as shown at the following figure.

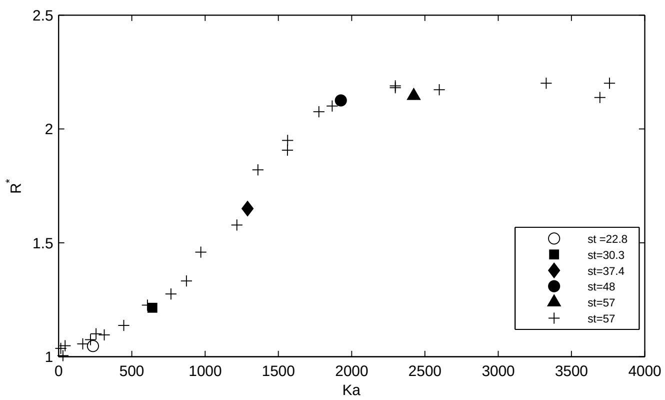

Figure 1: $R^{\star}$ as a function of Ka for several fluids. Surface tension is in mN/m.

Based on the high solubility and diffusivity of iso-propanol in water, we argue that these solutions behave as pure liquids with reduced surface tension [3]. Indeed, low-frequency inlet disturbances turn in the unstable regime into solitary humps preceded by capillary ripples, as predicted by theory for simple liquids [4]. The characteristics of these coherent structures correlate satisfactorily with the reduced Re number δ defined as $\delta = Re^{11/9} 5 Ka^{1/3} 3^{7/9}$ (Figure 2).

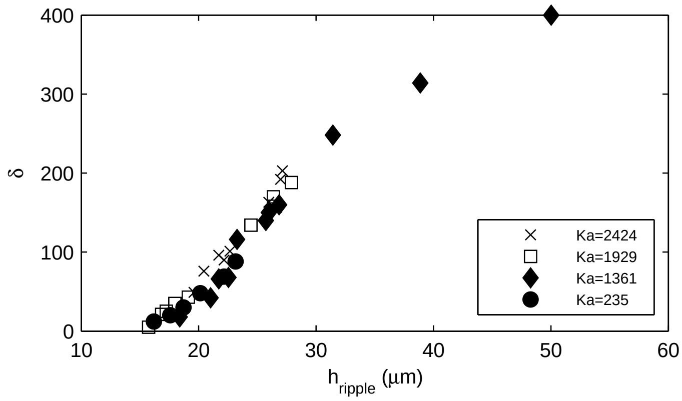

Figure 2: $R^{\star}$ as a function of Ka for several fluids. Surface tension is in mN/m.

Aqueous solutions of SDS exhibit a remarkably different behavior, with more pronounced feature the strong damping of all inlet disturbances. In particular, the typical for simple fluids steepening and acceleration of wave crests (which is arrested by the development of front-running capillary ripples and leads to viscous solitary waves) is never observed even at very high Re. The dominant structures for almost the entire range of inlet frequencies tested are sinusoidal traveling waves (Figure 3) of very small amplitude. The characteristics of these waves are documented, and are interpreted in terms of the visco-elastic properties of the surfactant monolayer, and in particular the dilational surface elasticity. Though most relevant wavelengths are in the gravity regime, the effect of the surface layer is critical, as has already been shown in a different context [5].

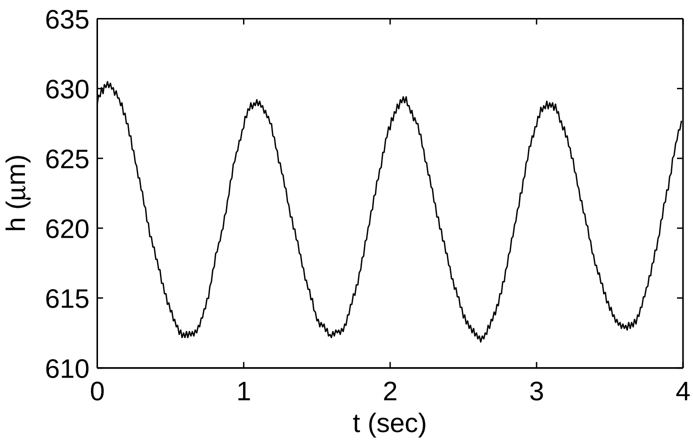

Figure 3: Film thickness for SDS 0.1 cmc solution at 7 inclination agle. The corresponding Re is 103.

References

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